FINAL REPORT

Using Cognitive Principles to Design Multimedia Training Environments to Support Learning

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As implied in the table of contents below, shall we attach copies of the ICLS conference papers and a copy of the PML paper to this final report?

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Project Summary

(Summary of research carried out under ONR Grant No. N00014-95-1-0790.)

This document serves as the final technical report of ONR Grant No. N00014-95-1-0790.

During this project we examined factors that influence how well people learn from multimedia systems. Our project focused on developing multimedia systems to support human learning, based on cognitive principles and guidelines from cognitive science. The question was not so much whether multimedia makes a difference, but rather how can it best be deployed to make a difference? Specifically, what combinations of media and methods of interaction are most effective for learning, and why?

Multimedia modules are frequently organized along physical media (e.g., text, graphics, video). Our work has been based on another way of thinking about the problem of how to organize the content. Thus, a learner at a given moment may want to see an *example* as opposed to a definition. The example might be text, graphics, video, etc. Thus, the physical media (text, graphics, etc) can be largely divorced from the "cognitive" media (example, definition, etc). Finally, our work is also significant in that it provides the beginnings of an adaptable multimedia presentation system that can adjust its content according to the learning needs of the user.

In domains such as chemistry (ChemLab) and programming (AlgoNet2) we manipulated features of the learning environment in order to examine whether certain aspects of the training environment--such as whether the learner is given the opportunity to actively construct things and how the learner is able to navigate through the environment--affect learning. As we progressed in these endeavors we came to believe that a major determinant for the creation of a successful multimedia learning environment would be the availability of tools that allow the content expert (e.g., the chemist, physicist, chef, or carpenter) to describe the relevant knowledge in a domain and to indicate relationships among bits of knowledge in that domain in a relatively simple way. Thus, we came to develop a Procedural Markup Language (PML) for knowledge specification. PML provides a way to lay out knowledge without the concern about how the knowledge would actually be presented in a multimedia training system. Other modules for presentation could be created to deal with presentation. PML was designed to make the knowledge specification task as direct as possible. Our assumption is that unless the knowledge base is specified in a clear and complete way (relatively speaking), any attempt to make the actual delivery of that information effective is likely to fail. So, we have focused towards the end of the project on making PML as straightforward and robust as possible.

The project has yielded two proceedings papers and an under-review journal paper that are listed following this summary and are also attached.

Empirical Studies

We conducted several studies to examine the effects of cognitive media types and self-explanations on learning in multimedia systems. One experiment was in the domain of chemistry (determining molecular shapes) and the other was in the domain of computer graph theory. The major findings were that the type of learning orientation induced in students when interacting with different versions of the systems leads to different browsing (through the system) patterns but does not appear to lead to differences in test performance. The difference in browsing patterns has implications for the types of "orienting" tasks one might want to give learners as they learn a new domain. Clearly some tasks engage the learner in the material more deeply while other tasks encourage the learner to skim much of the material in order to get to the "important" parts.

We have been developing a new training multimedia system in home repair (specifically,

plumbing). This new system builds on our initial findings for training in chemistry and graph theory as well as our notions about factors affecting navigation. We are attempting to create a system that allows learners to access information in multiple ways. For instance, a person might wish to know how water enters the home plumbing system, or how to repair a leaky faucet, or how to replace a washer. These questions reflect different goals and possibly background knowledge of the learner and thus, a training or help system should reflect these different goals by helping the learner traverse different paths through the system tailored to the goal. In addition to the system taking into account the learner's/user's goals, there is also the issue of how to best interact with the system. Queries could be based on a graphical interface that provides a schematic of a home that the user can systematically zero-in on in order to let the system know the components of interest. Alternatively the interface could be menu driven. Another option is a quasi-natural language interface. Our future work may explore these different interaction possibilities as well as examine the effects of different user goals on how the system is used and on how effectively the learner acquires/finds information. Finally, the system will provide information in various media (text, graphics, animations, videos) and although initially we will hold these media constant across learners (while we focus on navigation issues) we will ultimately also manipulate the media and examine the effects on learning.

Creating a Generalized Architecture for Cognitive Multimedia Learning Environments

Our other major thrust has been to continue to work toward a generalizable architecture for cognitive multimedia learning environments. We have developed a knowledge structure based on cognitive multimedia theory that we hypothesize can be used to support students in learning how to conduct procedures (from repair to troubleshooting to installation) in any domain, using a wide variety of approaches (from direct instruction to scaffolded apprenticeship, from menu-based navigation to virtual reality, and from text-only to full-video multimedia content). Our first step toward testing our generalizability hypothesis has been to construct a simple educational application structured with this architecture. The example domains that we have chosen are plumbing and cooking. The content, for plumbing, includes how to clear a clogged drain, how to install a toilet, and how the hot water system works at an abstract level.

Procedural Markup Language (PML)

We decided to design and develop a markup language which would allow us to represent linkages between knowledge elements at a symbolic level. We are referring to this language as PML (Procedural Markup Language). PML is composed of knowledge nodes connected by links and includes cognitive multimedia slots. Knowledge nodes are of three types: things, states, and procedures. The links between nodes are typed as well. More information on PML can be found in the attached under-review paper "PML: Representing procedural domains for multimedia presentations."

PML (and the tkpml tool for specifying the PML graphically; see below) provides a way for content developers to specify the knowledge in a domain and to specify the links among bits of knowledge. The resulting knowledge representation, including the cognitive and physical media, can then be used to develop actual HTML pages. Thus, developers will have a system for creating content and specifying relations in a way that can be used to create flexible web pages.

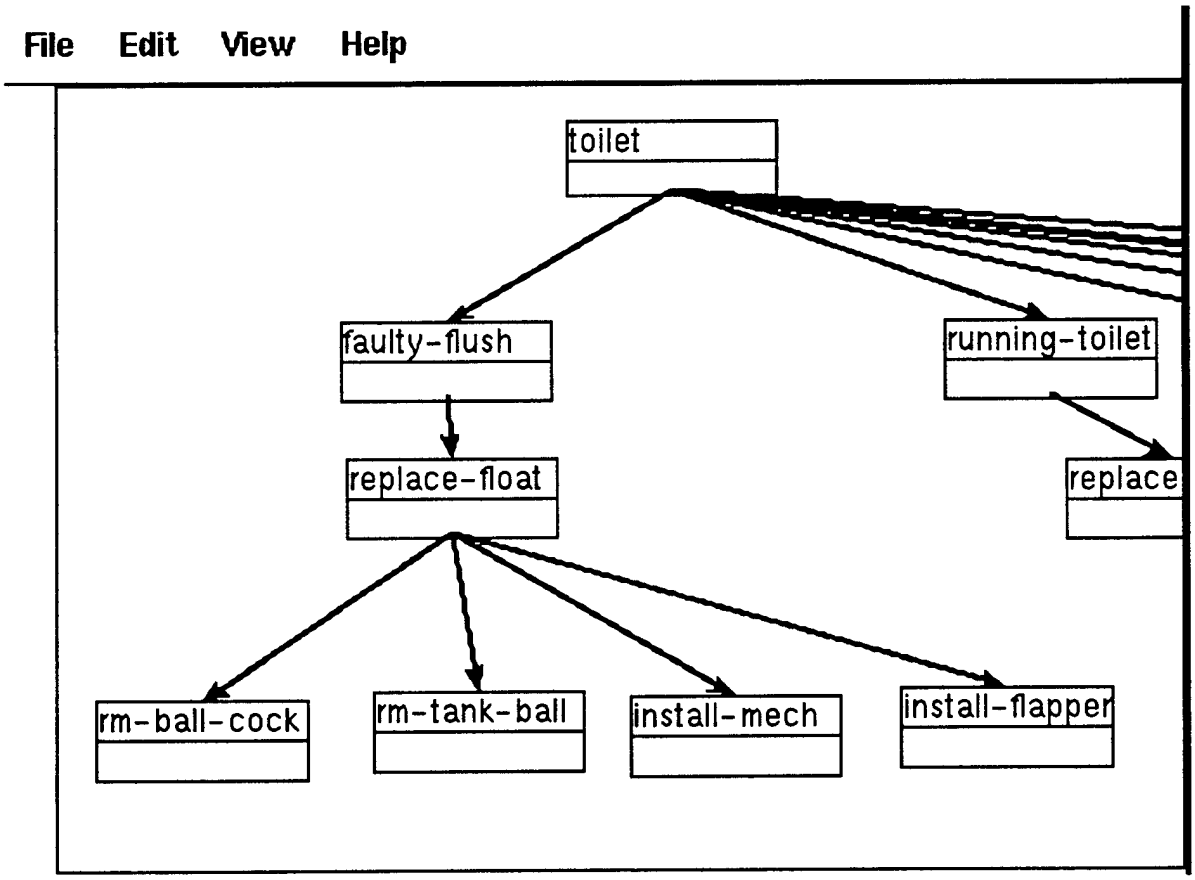
tkPML: Creating a Tool for Developing a Knowledge Base

In order to facilitate the authoring of PML documents, we have developed a graphical editing tool called tkPML which can be used to create the knowledge node/link networks graphically (one of our grad students, Scott McCrickard, has been the primary developer of the software). The tkPML graph creation interface replaces the tedious, mistake-prone task of entering the node and edge information by hand with a point-and-click interface with form fill-in for the text entry. We expect

that this tool will help designers to better establish and maintain mental models of their PML representations.

In tkPML, nodes and links can be created and positioned with simple mouse actions, and the layout can be seen at various levels of detail to obtain an overview of large graphs as well as a more informative view of a smaller number of nodes. Each node can be expanded to view and change the knowledge contained in it. Below is a screen shot showing various nodes being linked.

tkPML files are saved in an augmented PML format, with node locations, which is not part of the standard PML definition, saved as comments. Thus, designers can edit the saved files by hand or run presentation interpreters on the files without modification. In addition, tkPML can import files written in PML, even files which were not created using tkPML (the node locations are generated automatically). This allows designers to familiarize themselves with PML representations without wading through lots of code.



Nodes are created by double clicking on the background and are moved by dragging on the top "title" portion of the node. Links are created by dragging from the bottom "link" portion of one node to another. Double clicking on an existing node pops up a node information screen which allows a designer to edit information about the node.

For cognitive media information, users can edit the ID, title, author, and type. The "Edit..." button pops up the media window (shown in the middle) and the "Edit appspecific" button pops up the application-specific window. The media window allows a user to add media nodes within a

knowledge node. A media node can be selected in the listbox and edited in the display area. The media nodes can be textual descriptions or names of files containing multimedia information. The application-specific window is used to enter application-specific information, that is, information that is not in the PML specification but is important for this PML instance.

Translating the Knowledge Base into HTML

In order to create a presentation based on a PML document, we are developing a PML interpreter which can interpret PML descriptions, retrieve the appropriate media in those descriptions, and create a hyperlinked presentation based on the situation and needs of the user (this effort is being headed by Coleen Kehoe, an unpaid graduate student involved in the project). For example, if a novice user is considering whether to call a plumber to repair a leaky shower, the system need not display all the details of the repair procedure but instead may choose to summarize the time, expertise, and tools necessary to perform the procedure. If the same user has previously repaired a leaky faucet, the system may display an overview of the repair procedure (the top-level steps) and provide links to the sub-substeps that are different from the previous procedure that the user has experience with. Truly interactive and dynamic multimedia systems will need such capabilities, and PML is designed to support the development of such systems.

We implemented the core architecture (in Java) that would display content based on student experience and a set of display rules (in a production rule format); basically, the core is a cognitive multimedia display engine. The idea is that content would be provided to the display engine along with a set of rules for how to present this content and a memory of information that the user had already provided, e.g., "If the user has identified the problem as a leaky faucet, present the known causes for a leaky faucet along with links to the procedures for testing for each of those causes." Next, we needed content and a sample set of rules.

Project Publications and Reports

Journal Publications

None.

Papers in Preparation for Journal Submission

Ram, A., Catrambone, R., Guzdial, M.J., Kehoe, C.M., McCrickard, D.S., & Stasko, J. (under review). *PML: Representing procedural domains for multimedia presentations.*

Papers in Refereed Conference Proceedings

Byrne, M., Guzdial, M., Ram, P, Catrambone, R., Ram, A., Stasko, J., Shippey, G. Albrecht, F. (1996). The role of student tasks in accessing cognitive media types. In *Proceedings of the International Conference of the Learning Sciences.* Charlottesville, VA: Association for the Advancement of Computing in Education, 114-119.

Shippey, G., Guzdial, M., Ram, A., Catrambone, R., Albrecht, F., Byrne, M., Roberts, J., Stasko, J. (1996). Exploring interface options in multimedia educational environments. In *Proceedings of the International Conference of the Learning Sciences.* Charlottesville, VA: Association for the Advancement of Computing in Education, 496-501.

Paper Presentations

Byrne, M., Guzdial, M., Ram, P, Catrambone, R., Ram, A., Stasko, J., Shippey, G. Albrecht, F. (1996). *The role of student tasks in accessing cognitive media types.* Paper presented at the International Conference of the Learning Sciences (Chicago, November).

Guzdial, M., Catrambone, R., Byrne, M., Shippey, G., Albrecht, F., Ram, A., Stasko, J., Ram, P., & Roberts, J. (1996). *Task and interface issues in accessing cognitive media.* Paper presented at the Office of Naval Research Workshop on Issues in Interactive Multimedia (Las Cruces, NM, February).

Shippey, G., Guzdial, M., Ram, A., Catrambone, R., Albrecht, F., Byrne, M., Roberts, J., Stasko, J. (1996). *Exploring interface options in multimedia educational environments.* Paper presented at the International Conference of the Learning Sciences (Chicago, November).

Web-Based Materials

Various components of the system are available for inspection at:

http://www.cc.gatech.edu/gvu/cognitive/cognitive-multimedia/home.html

tkpml screen shots are in: http://www.cc.gatech.edu/grads/m/Scott.McCrickard/tkpml/
tkpml-main.gif shows the main tkPML screen displaying the toilet example
tkpml-nodeinfo.gif shows the popup window for entering node information
tkpml-editinfo.gif is the window for entering information for a single cognitive media instance
tkpml-appspec.gif is the window for entering application-specific information

PML: Representing Procedural Domains for Multimedia Presentations

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Abstract

A central issue in the development of multimedia systems is the presentation of the information to the user of the system and how to best represent that information to the designer of the system. Typically, the designers create a system in which content and presentation are inseparably linked; specific presentations and navigational aids are chosen for each piece of content and hard-coded into the system. We argue that the representation of content should be decoupled from the design of the presentation and navigational structure, both to facilitate modular system design and to permit the construction of dynamic multimedia systems that can determine appropriate presentations in a given situation on the fly. We propose a new markup language called PML (Procedural Markup Language) which allows the content to be represented in a flexible manner by specifying the knowledge structures, the underlying physical media, and the relationships between them using cognitive media roles. The PML description can then be translated into different presentations depending on such factors as the context, goals, presentation preferences, and expertise of the user.

1. Introduction

Suppose that you are a homeowner faced with the problem of a leaky faucet. If you are reasonably comfortable with home repair, you might be able to just plunge on in and make the repair. But if you are not familiar with that kind of repair, you might seek help, perhaps using a book or even one of the new multimedia guides to home repair for your PC. Will the book present the information you need at the level you need it? Maybe you know some repair well in general, but don't know faucets. Then you probably want a book that presents the key steps, but without a lot of detail. But if you are a novice at home repair, you probably need a lot of examples (with photos and diagrams) and detailed descriptions. In the case of both the book and the multimedia guide, you may encounter the problem of reading the book or the PC screen while your hands have tools in them and you are in the midst of the repair.

This hypothetical scenario is the focus of our research. How can information be presented, dynamically, to meet the needs and prior knowledge of the learner? How should content be encoded so that the developer can present information tuned to the audience and perhaps even presented in the medium of choice?

One of the central issues in the development of multimedia systems, whether on the Web or as a standalone system, is the representation of the content, that is, the information that is to be displayed to the user of the system. For example, an educational system that teaches chemistry must contain information about atoms, molecules, and gas laws; a training system for computer technicians must contain information about memory chips and buses; and a Web site for amateur home repair must contain information about kitchens, showers, and faucets. In designing such systems, however, one must attend not only to the knowledge to be represented but to how that information is to be presented. Is the system's information about showers to be displayed in graphical form? Is information about installing memory chips to be displayed as an itemized list of textual imperatives? Is information about gas laws to be displayed using an animated video clip showing the movement of molecules as a gas is compressed? Typically, the system designer must consider both content and presentation and, in doing so, create a system in which the two are inseparably linked; a specific presentation is chosen for each piece of information, perhaps combining several available media such as text, pictures, animations, and sound, and hard-coded into the system so that it is available for presentation in exactly the form that the system designer intended. Specific navigational aids are also chosen and hard-coded into the system so that a predetermined hypermedia structure is encoded and available to the user.

We argue that *knowledge representation* and *presentation design* should be treated as separate activities. The knowledge engineer or content designer should focus on the knowledge that is being represented: what is known about molecules, buses, and faucets, how this knowledge is structured, and how it might be represented using basic media elements. The presentation designer should focus on the multimedia presentation of this knowledge: how should a diagnostic procedure be displayed to the user? At what level of detail, and for what level of expertise should it be presented? What should it be linked to? What navigational aids should be provided? What issues concerning how people comprehend text, graphics, animations, etc. need to be considered?

Such an approach has several benefits. First, it is easier for domain experts (who may not be presentation experts) to build the knowledge representation without regard to how the information will ultimately be displayed. Second, it is possible to design different presentations for the information based on the user's level of expertise, or on the task that the user is engaged in (for example, learning vs. troubleshooting), or on other factors. Third, this approach permits the development of truly interactive multimedia systems in which the system creates appropriate presentations on-the-fly based on the current interactions and context. Only the knowledge needs to be specified beforehand, but whether a diagnostic procedure, for example, is presented as an itemized list of textual bullets, a graphical flow chart, an animated movie, or some combination thereof can be determined dynamically. If knowledge and presentation were tightly coupled, all these presentations would have to be created manually in advance and stored as alternative depictions of the same information.

Of course, the knowledge representation must ultimately bottom out in media: a textual definition of a gas law, a photograph of a faucet, or a schematic of a VLSI chip. Thus, it is important to provide a principled means of coupling the knowledge representation structures with the underlying media, but in a manner that provides the flexibility needed for interactive and dynamic presentations. We argue that knowledge structures should organize media according to their *cognitive role* [Recker, Ram, Shikano, Li, & Stasko, 1995]. Consider, for example, a student who is using an educational multimedia system to learn chemistry, or a homeowner who is using a home repair CD-ROM or Web site to help fix a leaky faucet in a bathroom. The user is unlikely to say, "I would like to see some text now" or "I could really use a WAV sound file now." Instead, the user may say, "I could really use an example," leaving it up to the system to determine whether that example is best presented as text, sound, animation, or some combination thereof. In other words, we argue that multimedia content, consisting of *physical media* such as text, sound, video

clips, and so on, should be organized and coupled to knowledge structures using *cognitive media roles* , such as definition, example, simulation, worked problem, and so on. A cognitive media role, such as "example," specifies the function that the information plays in the cognitive processes of the user. The user might ask for an example of a faucet or a simulation of molecular forces, which in turn would be displayed using an appropriate combination of physical media as determined statically by the presentation designer and/or dynamically by the system itself.

There has been a significant amount of work attempting to disentangle knowledge representation from presentation in multimedia. Maybury [1993] has emphasized this distinction in his work with intelligent multimedia interfaces. Feiner [Feiner, McKeown, 1991] has shown a system that can actually construct multimedia representations on-the-fly, drawing from a knowledge base of content and a separate knowledgebase about representations. Research teams such as the Hyper-G group in Austria [Tomek, Maurer, & Nasser, 1993] have created Web-based applications that allow for separation between representation and presentation (e.g., keeping link information separate from the multimedia document itself). What we add to the existing science is (a) a theory of effective organization for multimedia used for**learning** (specifically, cognitive media roles), and (b) a notation for encoding knowledge such that an effective representation can be generated.

To facilitate the development of a system outlined above, we propose and describe in this article a new notation called Procedural Markup Language (PML). PML is a markup language written in XML that allows the content designer to encode domain knowledge in an intuitive and flexible manner by specifying the knowledge structures, the underlying physical media, and the relationship between them using cognitive media roles. We focus specifically on procedural task domains, in which the primary type of knowledge to be represented concerns the performance of procedures. The highlights of our formalism are:

- Information about a domain (e.g., plumbing) is encoded in *knowledge nodes* that have connections, called *knowledge links,* to other knowledge nodes.
- Information within a particular knowledge node (e.g., information about a faucet) is represented using *physical media clusters* containing media elements such as text, graphics, animations, video clips, and sound files.
- Physical media are organized under knowledge nodes using *cognitive media roles* , such as "definition," "example," etc. Any cognitive media role under a knowledge node could potentially contain one or more different physical media (e.g., an example of a faucet might be represented using some text and a graphic).
- The information contained in the combination of knowledge nodes, knowledge links, physical media clusters, and cognitive media roles forms the raw material that can be used by a presentation system to determine what the user or learner will see and hear, and what navigational connections and devices will be available on the screen. Different presentations may be created from the same underlying representation, depending on various factors such as the expertise of the user in the domain, the information that the user has previously seen, the current goal of the user, and so on.

In this article, we use the home repair domain as our example, and show how PML can be used to represent information about, for example, repairing a leaky faucet. The PML representation is independent of the particular presentation that is ultimately constructed. We show that the same PML representations can be used to create different presentations. Since we have focused primarily on the development of PML, our current implementation the presentation-construction system is fairly simple. Ultimately, we are interested in more sophisticated presentation-construction systems which can dynamically create an appropriate presentation based on the goals or tasks of the user, the user's level of expertise, the context, and other appropriate factors.

2. Technical Details: Knowledge Representation

PML consists of *knowledge nodes* that represent concepts and *knowledge links* that represent relationships between knowledge nodes, similar to the semantic net structures used for knowledge representation in artificial intelligence systems. However, unlike semantic net systems which are used for reasoning, nodes do not contain slot-filler representations of concepts; for multimedia presentations, nodes need to contain media that can be used to create presentations of those concepts for the user. Media are stored in *physical media clusters* that contain text, pictures, sounds, video clips, etc., that are the basic elements describing concepts. Media clusters are organized under knowledge nodes using *cognitive media roles* that represent the cognitive role (e.g., example, definition) played by the media elements in describing the concepts in the knowledge nodes. A cognitive media role, such as an example, may have one or more physical media clusters associated with it, where each cluster represents a different example. This structure is summarized in Figure 1.

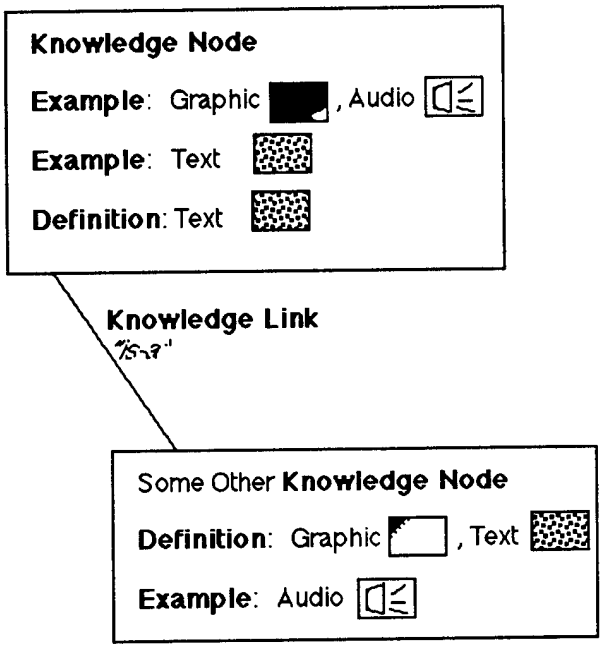

Figure 1: General Structure of Knowledge in PML Representations

Before describing the markup language itself, it is instructive to look at the representational structures that the language will need to encode. Let us briefly discuss the necessary nodes and links.

Knowledge Nodes

A knowledge node represents a concept that the system knows about. Information about the concept is represented using media clusters while relationships between concepts are represented using knowledge links. Following basic ontological principles that are commonly used in representations systems in artificial intelligence and cognitive science, we divide the entities being represented into *things* , *states* , and *procedures* (see Table 1). Based on our experience with several different domains, this ontology appears to sufficient to capture the distinctions necessary to represent our target domains where the knowledge being represented is mainly procedural. In general, though, the robustness of the language can only be determined by representing a large number of domains using this formalism.

Table 1: Knowledge Nodes

Name	*Description*	*Examples*
Thing	Represents a system, physical object, part, or substance in its normal state. Things may be composed of other things.	Hot water system (system). Faucet (physical object). Washer (part). Water (substance).
State	Each thing has one or more states that it can be in. A thing's normal state is the usual operational state of that thing; other states represent problem conditions that may need repair. Usually only problem states are represented explicitly; the main representation of a thing is assumed to represent its normal state.	Pilot light off. Faucet leaky. Washer worn out. Water is brown.
Procedure	Represents a sequence of actions carried out by the user that operate on a thing in some manner. The actions that comprise a procedure may themselves be procedures; ultimately, this bottoms out when the "primitive" action is operationalized and can be directly carried out by the user.	Lighting a pilot lamp. Replacing a leaky faucet. Installing a shower.

Knowledge Links

Knowledge nodes may be linked to other knowledge nodes using knowledge links that represent conceptual relationships between those knowledge nodes (see Table 2). Note that knowledge links are strongly typed; for example, the **precondition** link always connects states to procedures. The

›rder in which multiple links of the same type are listed under any givennode is not significant, with the exception of **steps** which are listed in the ›rder in which they should be carried out. Knowledge links may be traversed in either direction by the system, although each link has an explicit ource and destination endpoint. The reverse links are also listed in Table 2. These reverse links are managed by the system and not manually reated by the user. Our formalism provides the following set of knowledge links; as before, determining the sufficiency of this set is an empirical ¡uestion, although this set has been adequate for several domains that we have investigated.

Table 2: Knowledge links

Name	*Description*	*Examples*
Is-a	Thing **is-a** Thing Represents the broader category of a thing, or (the other direction) the particular types of a thing. The reverse link is **subtype**.	Single-lever faucet **is-a** Faucet Faucet **subtype** single-lever faucet Pilot light **is-a** Ignition device
Is-a	Procedure **is-a** Procedure Represents the broader category of a procedure, or (the other direction) particular styles of a procedure. The reverse link is **subtype**.	Plunge-drain **is-a** unclog-drain Unclog-drain **subtype** plunge-drain
Has-a	Thing **has-a** Thing Represents a subsystem of a system or a part of a physical object. Only things can have parts, which are other things. The reverse link is **part-of**.	Water heater **has-a** Pilot light Pilot light **part-of** water heater Faucet **has-a** Washer Hot water system **has-a** Shutoff valve Hot water system **has-a** Stepped pipes Hot water system **has-a** Water heater
Connects-to	Thing **connects-to** Thing Represents contiguous or connecting pieces of an overall physical system. The overall physical system, represented as a thing, would have **has-a** links to the individual things comprising it as well. The reverse link is **connects-to**.	Shutoff valve **connects-to** Stepped pipes **connects-to** Water heater **connects-to** Hot water supply line
Steps	Procedure **steps** Procedure Represents the substeps of a procedure, that is, steps that represent the procedure in more detail (these steps may, in turn, be further broken down into substeps). An experienced user may choose not to see this level of detail. There is an implied ordering of the steps of a procedure. The reverse link is **step-of**.	Replace washer **steps** (Unscrew nut; Remove washer; Insert new washer; Replace nut) Unscrew nut **step-of** Replace washer
Problem-state	Thing **problem-state** State Links things to the problem states that those things can be in. A problem state is an abnormal state that requires repair. A thing may have multiple problem states. The reverse link is **problem-state-of**.	Water heater **problem-state** Pilot light off Pilot light off **problem-state-of** water heater Faucet **problem-state** Faucet leaky Facuet leaky
Repair-procedure	State **repair-procedure** Procedure Links a problem state to a procedure that, if successfully completed, repairs the problem and returns the thing to its normal state. A problem state may have multiple repair procedures. An installation procedure is also represented as a repair procedure. The reverse link is **repair-procedure-for**.	Pilot light off **repair-procedure** Relight pilot light Relight pilot light **repair-procedure-for** pilot light off Faucet leaky **repair-procedure** Repair leaky faucet No bathtub in bathroom **repair-procedure** Install bathtub

Outcome	Procedure **outcome** State Links a procedure, which could be an entire procedure or an individual primitive step within a procedure, to the states that result from carrying out that procedure. The state may be presented to the user as evidence that the procedure was successfully carried out. A procedure may have more than one possible outcome. The reverse link is **result-of**.	Tighten washer **outcome** Water does not leak through Water does not leak through **result-of** tighten washer
Outcome	State **outcome** State When there is no intentional intervening action, an outcome link may link a state directly to another state that may result. The reverse link is **results-from**.	Faucet leaky **outcome** Basement wet Basement-wet **results-from** faucet leaky
Precondition	State **precondition** Procedure Links the preconditions or enabling conditions of an action to the node that represents that action. The reverse link is **requires**.	Pilot light off **precondition** Open water heater access panel Open water heater access panel **requires** pilot light off
Uses	Procedure **uses** Thing Links procedures to tools, instruments, and other objects that are used in that procedure. The rese link is **used-in**.	Shut off water **uses** Monkey wrench Monkey wrench **used-in** shut off water
Related-to	Links any node to any other node that may contain related or relevant information. Used (sparingly!) to represent any relationships not specifically captured by existing link types. The reverse link is **related-to**.	Hot water system **related-to** Heating system Install faucet **related-to** install shower Washer **related-to** Repair leaky faucet

Physical Media Clusters

A physical media cluster (or simply media cluster) contains the actual information about a knowledge node that the system can display to the user. We will see below that all media are stored in separate files, referenced via the MEDIA tag, with the exception of text which may be included in-line in the PML document for authoring convenience. A media cluster may contain more than one type of physical media (text, video, etc.). A knowledge node may contain one or more media clusters; these are organized using cognitive media roles that provide the connections between the knowledge structures and the media clusters.

Cognitive Media Roles

The media clusters within a knowledge node are organized in terms of the cognitive roles they play in the problem-solving task in which the user is engaged. For example, a particular mixed-media text-and-pictures description of a faucet may serve as an "example" of a single-lever faucet; in this case, the knowledge node for "single-lever faucet" will contain an "example" role which contains a media cluster that represents that text-and-pictures description. Our formalism provides the following cognitive media roles [Recker et al., 1995].

Table 3: Cognitive media roles

Name	*Description*	*Example*
Name/ Title	The name of the item being represented in the knowledge node. Usually one or a few words of text.	"Pilot light."
Definition/ Description	The definition of the concept being represented in the knowledge node or, more informally, its description. Usually a textual description accompanied by diagrams.	"A pilot light is a small gas flame that is continually burning. It is used to light the furnace when ... ..." [Schematic of pilot light]
Example	An example of the concept being represented in the knowledge node.	[Photograph of an actual pilot light] "This is an example of a pilot light. In this design, the small lever to the left [pointer to picture] is used to ..."
Counter-example	An example of an alternative design, an alternative state, etc.	[Photograph of a flint-based lighting system.] "An alternative to the pilot light is the ..."
Justification	An explanation of a step being carried out in a procedure, or an explanation of the functional role of a thing that is part of a larger thing.	"You want to turn off the water at the supply first because ..." "Faucets have O-rings because..."

Example

To illustrate how these nodes and links fit together to provide an overall representation of the domain of interest, consider a snippet of the representation of faucets from the home repair domain, shown in Figure 2 in pictorial form.

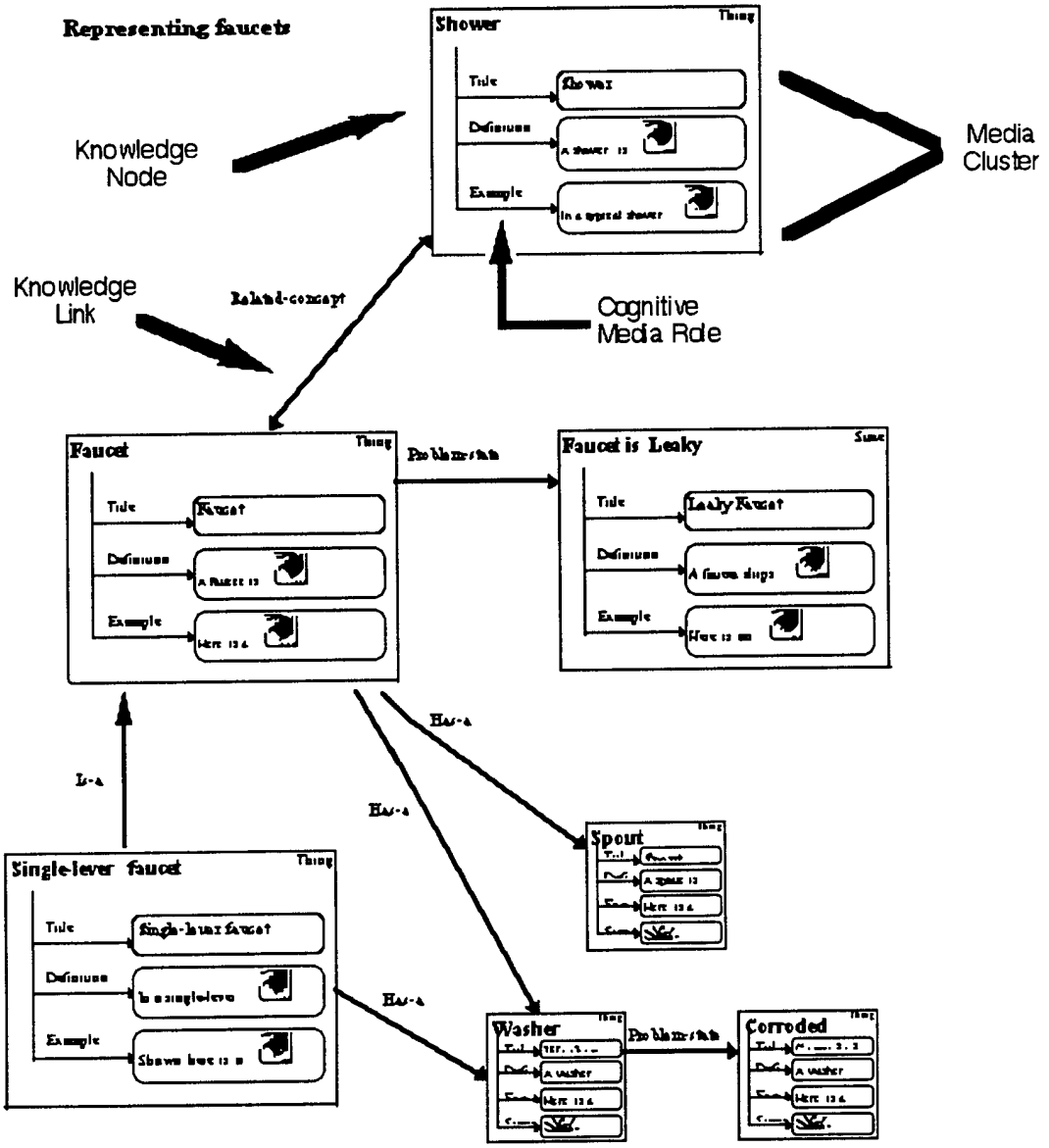

Figure 2: Pictorial form of a PML knowledge structure about faucets.

3. Technical Details: Procedural Markup Language

The previous section described our knowledge representation framework. Briefly, knowledge is organized into nodes (concepts) that are linked by relationships. Each node organizes physical media into clusters corresponding to roles for the media. This was summarized in Figure 1. In this section, we describe the notation that we use for articulating this representation.

We have developed a language called PML that allows authors to encode our knowledge representation in a set of files. Authoring in PML is analogous to authoring in HTML or other markup languages, but with the crucial difference that the author focuses on representing information about the domain and not primarily on information about presentation. That is, the two types of information are decoupled. For example, if one were to create a Web page in HTML describing how to install the latest release of a piece of software, one might do this as follows:

```
To install this release, perform the following steps: <BR>
<OL>
<LI> Download the file.
<LI> Unstuff the file.
<LI> Double-click on the installer icon.
</OL>
```

Notice that the procedure is described using a series of steps, but in order to state the steps one has to choose a particular physical representation (here, a numbered list of items). Using PML, however, one would specify the steps independent of the presentation:

```
<PROCEDURE ID="install">
```

```
<TITLE>Installing the software</TITLE>
<DESCRIPTION>To install this release, perform the following steps:</DESCRIPTION>
<LINK TYPE="steps"
      <TARGET ID="download"/>      <TARGET
ID="unstuff"/>
      <TARGET ID="execute"/>
</LINK>
</PROCEDURE>
```

This example presents a *procedure* knowledge node with two cognitive media roles: *title* and *description*. The knowledge node has *step* knowledge links to separate "download," "unstuff," and "execute" procedure nodes that are represented using PML as well. Note that the PML does not specify whether to display the three steps as a numbered list, a flow chart, or as three separate pages with navigational arrows between them; that decision can be made independently and, if desired, dynamically (limited only by the physical media provided). Note also that the PML representation allows additional types of information to be represented, such as the preconditions and outcomes of the procedure, things that might go wrong and how to recover from them, justifications for the procedures, and so on. These could be hard-coded into the HTML representation too, but again the presentation would be static. Finally, the PML representation allows procedures and subprocedures to be represented hierarchically; the level of detail that is actually presented can be determined dynamically and should be dependent on factors such as the expertise of the user.

PML is written in Extensible Markup Language (XML) [Bray, 1998], a language for describing other markup languages. XML is a simplified version of Standard Generalized Markup Language (SGML) [Sperberg-McQueen, 1993], an international standard for creating structured documents. A markup language is essentially a set of tags that an author uses to describe parts of a document and a document that uses these tags is one kind of structured document. Currently, the most well-known markup language is HTML which contains tags like <TITLE>, <H1>, <IMG>, etc. While these tags are useful for describing basic document structure, they do not describe the content of a document very well. More powerful and most likely domain-specific markup languages are needed for this purpose and XML was developed as a common way to define these different markup languages. XML, however, has utility far beyond the World Wide Web; it can be thought of as a platform-independent way to represent knowledge in a machine-readable format. XML has already been used to specify markup languages for dozens of applications ranging from chemistry to electronic commerce [Cover, 1998]. Having a common way to specify these markup languages allows tools to be built that can work with any of the languages specified in XML. For example, we have developed a PML-to-HTML translator that uses a PML parser. This parser is generic, however, understanding XML and therefore any markup language specified using XML.

The notation used in XML descriptions is fairly standard (see [Bray, 1998] for details). Each ELEMENT statement is a production rule with the first item being the left-hand side of the rule and the second item (in parentheses) being the right-hand side. Every element corresponds to a tag in the markup language. A vertical bar indicates a choice and a comma indicates a sequence. The plus sign stands for "one or more" and the asterisk stands for "zero or more." An ATTLIST statement lists the attributes for a particular element (i.e. tag). It specifies the type of the attribute and whether it is required (REQUIRED) or optional (IMPLIED). The complete specification of our PML language is given in Table 4. Appendix A contains an annotated example PML representation of a snippet of an everyday procedural domain: baking a cake.

Table 4: Specification of PML

```
<!---- Things ---->

<!ELEMENT thing   (title, (author | description | justification | link |

appspecific | example | counterexample )*) >
<!ATTLIST thing          id
ID   #REQUIRED>


<!---- States ---->

<!ELEMENT state   (title, (author | description | justification | link |

appspecific | example | counterexample )*) >
<!ATTLIST state
          id   ID   #REQUIRED>


<!---- Procedures ---->

<!ELEMENT procedure   (title, (author | description | justification | link |

appspecific | example | counterexample )*) >
<!ATTLIST procedure
          id   ID   #REQUIRED>


<!---- Cognitive Media Types & Identifying Information ---->

<!ELEMENT title          (#PCDATA | media)* >
<!ELEMENT author         (#PCDATA | media)* >
<!ELEMENT description    (#PCDATA | media)* >
<!ELEMENT justification  (#PCDATA | media)* >
<!ELEMENT example        (#PCDATA | media)* >
<!ELEMENT counterexample (#PCDATA | media)* >

<!ATTLIST description
          type   CDATA
#IMPLIED>
```

```
<!ATTLIST justification
          type   CDATA
#IMPLIED>
<!ATTLIST example
          type   CDATA
#IMPLIED>
<!ATTLIST counterexample
          type   CDATA
#IMPLIED>


<!---- Media ---->

<!ELEMENT media  #PCDATA>
<!ATTLIST media
          src
CDATA    #REQUIRED
          caption   CDATA
#IMPLIED>


<!---- Links & Targets ---->

<!ELEMENT link   (target+)>
<!ATTLIST link
          type   (uses | is-a | has-a |
connects-to | related-to |
   steps | precondition | outcome | problem-state | repair-procedure) #REQUIRED>

<!ELEMENT target  EMPTY>
<!ATTLIST target

id            IDREF
#REQUIRED>


<!---- Application-Specific Key/Value Pairs ---->

<!ELEMENT appspecific   EMPTY>
<!ATTLIST appspecific

key           CDATA    #REQUIRED

value         CDATA    #REQUIRED>
] >
```

Authoring tools

n order to facilitate the authoring of PML documents, we have developed a graphical editing tool called tkPML that can be used to create the :nowledge node/link networks graphically (see Figure 3). As might be expected, textual hand-authoring of PML structures can be tedious and nistake-prone. The tkPML graph creation interface replaces the task of entering the node and link information by hand with a point-and-click nterface with form fill-in for the required text entry. We expect that this tool will help designers to better establish and maintain mental models of heir PML representations.

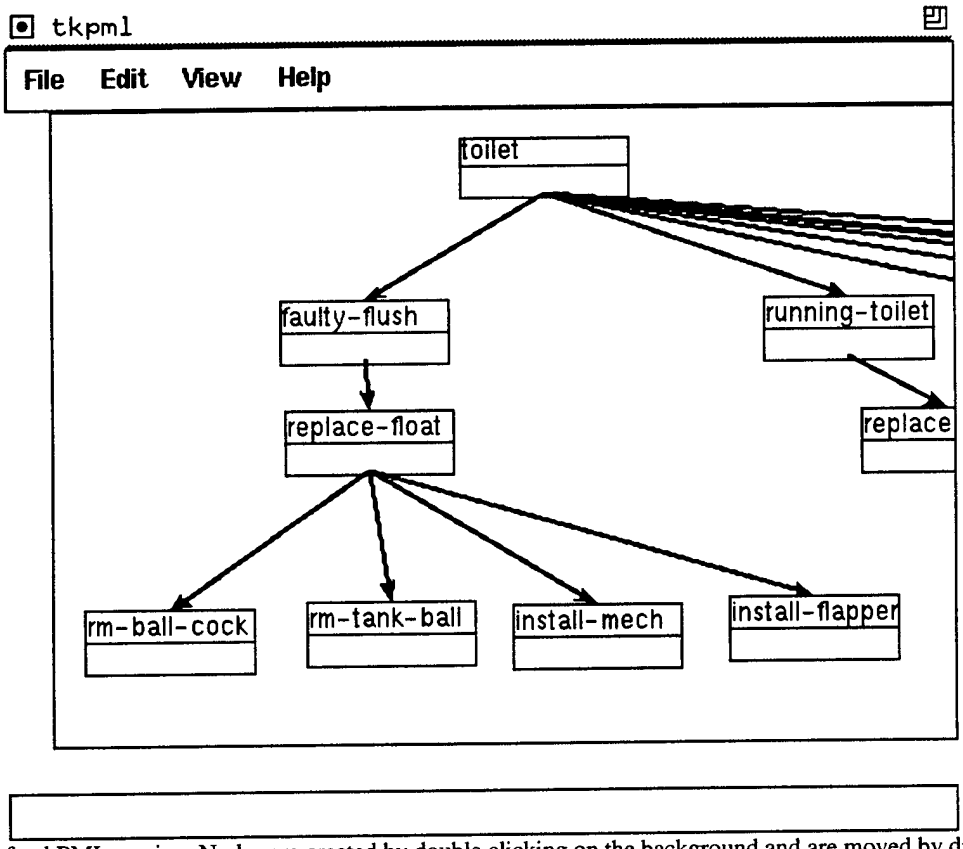

Figure 3: A screenshot of a tkPML session. Nodes are created by double clicking on the background and are moved by dragging on the top "title" portion of the node. Links are created by dragging from the bottom "link" portion of one node to another. Double clicking on an existing node pops up a node information screen (shown in Figure 4) that allows a designer to edit information about the node.

n tkPML, nodes and links can be created and positioned with simple mouse actions, and the layout can be seen at various levels of detail to obtain ın overview of large knowledge structures as well as a more informative view of a smaller number of nodes. Each node can be expanded to view ınd change the knowledge contained in it (see Figure 4).

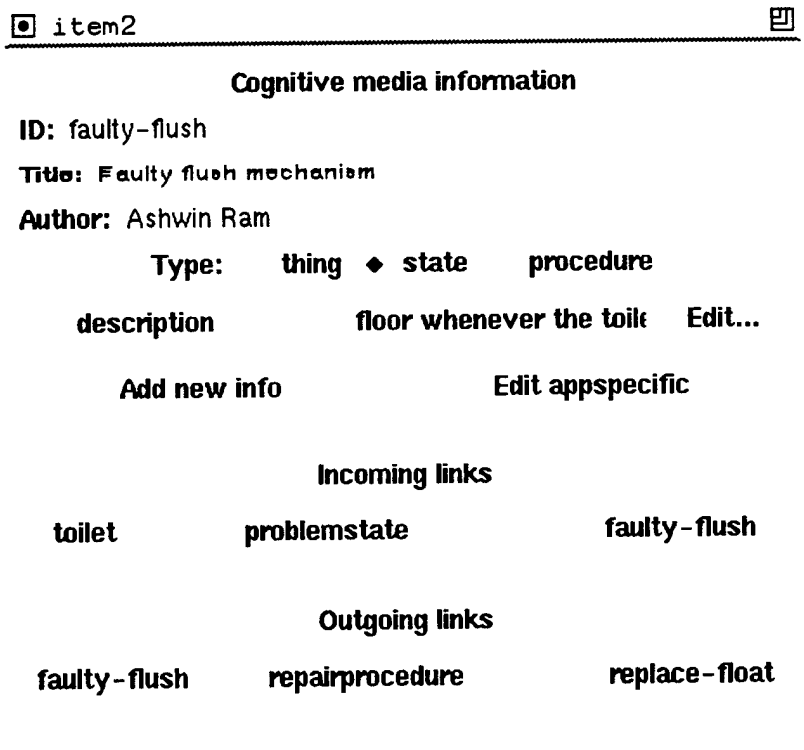

Figure 4: View of a knowledge node in the tkPML tool. In the top area are indicated the default cognitive media roles and the capability to add others. The lower area shows the incoming and outgoing knowledge links.

The tkPML tool saves a PML description file in an augmented PML format file. The one addition is simply node location, which is not part of the standard PML definition and is saved as a comment. Thus, designers can edit the saved files by hand or run presentation interpreters on the files without modification. In addition, tkPML can import files written in PML, even files that were not created using tkPML. For such files, tkPML uses a simple graph layout algorithm to generate an initial display.

As the name suggests, tkPML is written in Tcl/Tk, a platform-independent graphical scripting language that can run on Unix machines, PCs, Macintoshes, and within browsers over the World Wide Web [Ousterhout, 1994]. This allows PML representations to be exchanged and edited by users on different platforms and even published on the Web.

Presentation tools

In order to create a presentation based on a PML document, one may develop a PML interpreter-generator that can interpret PML descriptions, retrieve the appropriate media in those descriptions, and create a hyperlinked presentation based on the situation and needs of the user. For example, if a novice user is considering whether to call a plumber to repair a leaky shower, the system need not display all the details of the repair procedure but instead may choose to summarize the time, expertise, and tools necessary to perform the procedure. If the same user has previously repaired a leaky faucet, the system may display an overview of the repair procedure (the top-level steps) and provide links to the substeps that are different from the previous procedure with which the user has experience. Truly interactive and dynamic multimedia systems will need such capabilities, and PML is designed to support the development of such systems. The PML interpreter-generator would need to be based on principles of instructional and interaction design. PML is designed to support experimentation with such principles.

Alternatively and more simply, one may develop a PML interpreter that can construct a small number of predetermined presentations (such as one that always displays substeps in detail and another which always displays substeps as titles with links to the details) and use a simple heuristic to decide which presentation to use. We have chosen this approach for our initial implementation in order to test PML representations. Specifically, we have developed a PML-to-HTML translator that can create presentations based on simple, predetermined presentation rules (see Figure 5). This allows us to experiment with PML and gain knowledge that will facilitate later development of a fully dynamic presentation system.

Both of the presentations in Figure 5 are designed to help the user unplug a toilet drain using an auger. The left presentation is aimed at a novice, and the right presentation is aimed at an expert. For the expert, the basic steps are presented with minimal explanation, but with links that lead to more information, if desired. For the novice, more introductory information is provided (not shown) such as what an auger is, and each step is expanded with its explanation and any examples available for the step. Both of these presentations assume a web browser on a personal computer as the target platform. If the target were for, say, a handheld personal computer (which might be more useful when working in the bathroom) or even an audio presentation, a different structure should be generated (e.g., the handheld should not have a long scrolling presentation, as does the novice presentation depicted in Figure 5).

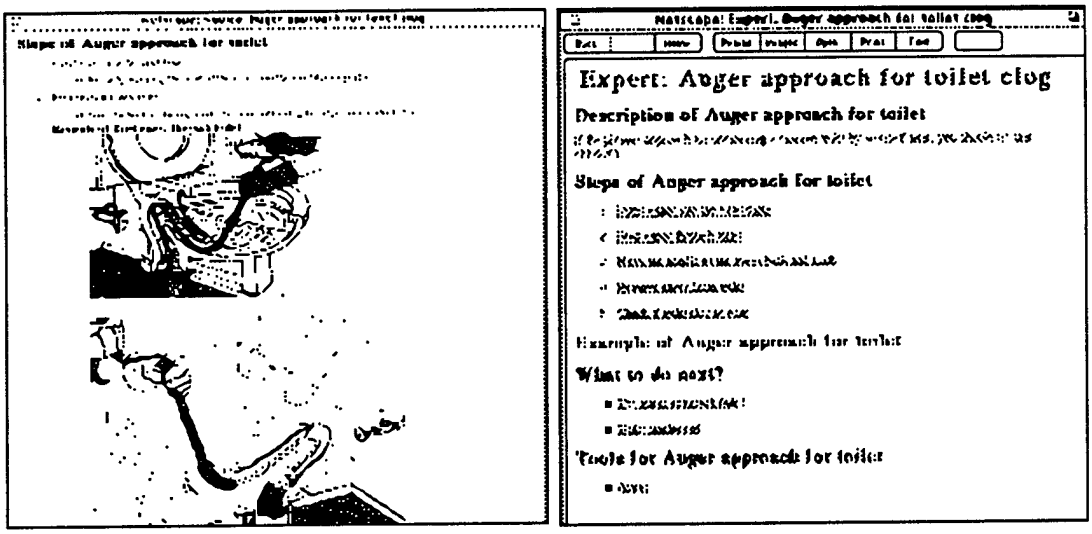

Figure 5: Two different presentations based on the same PML source

4. Conclusions

n this paper we present a new markup language called PML to facilitate the authoring of dynamic multimedia systems for procedural domains. We how how PML can be used to represent domain knowledge (concepts and relationships) independent of presentation issues and how this nowledge can be loosely coupled to presentation media via cognitive media roles. PML involves knowledge nodes connected by knowledge links. The knowledge nodes can contain cognitive media roles holding physical media clusters.

Cognitive media roles have been used succesfully in educational multimedia systems for teaching graph algorithms in an undergraduate computer cience course [Recker et al., 1995; Shikano, Recker, & Ram, 1998; Shippey, Ram, Albrecht, Roberts, Guzdial, Catrambone, Byrne, & Stasko, 996], and Lewis structures in an undergraduate chemistry course [Byrne, Guzdial, Ram, Catrambone, Ram, Stasko, Shippey, & Albrecht, 1996]. PML has also been used for other tasks and domains; we are using it to represent cases of object-oriented design and programming [Guzdial 1997], nd to encode process information about operations in an electronic assembly "Clean Room" [Realff et al., 1998]. While these earlier systems were ot dynamic, they do illustrate the generality and value of the knowledge representation and the notational tools.

n our own research, we are developing PML-based systems to investigate cognitive issues relevant in the design of dynamic multimedia systems. More broadly, in a learning situation, the goals that students bring to the learning task will affect their learning processes [Ram & Leake, 1995] and herefore a hypermedia support system for learning should have the capability to adjust itself in response to the user's goals. PML allows us to examine these issues empirically. For example, we would like to conduct systematic experiments that look at what factors actually play a role in the effectiveness of different presentations to the user or learner. For instance, is it really the case that a "high-level" presentation of a procedure for a nore knowledgeable person is more effective (measured, perhaps, in how well the person can do the procedure and how long it takes, counting presentation time) than providing him or her with all the details? In order to empirically answer questions such as these, we need a system capable of creating alternative presentations of some underlying information, which is precisely the goal of PML.

Acknowledgements

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** JS - MANY REFS FROM THE BODY ARE MISSING HERE.

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Appendix A

Table 5: Example PML file

```
<PML> # All PML documents must start with the PML tag

<PROCEDURE id="cake 1">
# This says we're beginning a procedure. We've given it an id of "cake 1."
# This is the name you use to refer to this procedure in other places.

<TITLE>How to Bake a Cake</TITLE>
<AUTHOR>Colleen Kehoe</AUTHOR>
# We define the title of this procedure and the author. Title is required.
# The title may be the same as the id in the procedure tag, if desired.

<DESCRIPTION>
This procedure tells you how to bake your basic cake. It assumes you're at or near sea level. You'll need a different
procedure if you're at a high altitude.
</DESCRIPTION>
# We give a description of the overall procedure.
# Since it is text, we can include it here or reference an external file via a MEDIA tag.

<JUSTIFICATION>
Everybody likes cake.
</JUSTIFICATION>
# We give a justification for this procedure. This is optional.

<APPSPECIFIC key="difficulty" value="easy"/>
# Here we may associate some application-specific information with this node.
# This may be used for indexing purposes or for deciding how to display this node.

<EXAMPLE>
<MEDIA SRC="cake.gif" CAPTION="Here is a picture of someone baking a cake."/>
<MEDIA SRC="cake.mov" CAPTION="Here is a movie of a baker at work."/>
</EXAMPLE>
# An example containing two physical media files.
# Any number of examples or counterexamples are allowed.

# Now we list all of this links from this node to other nodes in the system.

<LINK type="uses"> #This is a list of the equipment this procedure uses.
<TARGET id="mixer"/> #This is a "thing" node.
</LINK>

<LINK type="problem-state"> # The following nodes are problems.
<TARGET id="cake didn't rise"/> # Each is a "state" node.
<TARGET id="cake burnt"/>
<TARGET id="cake tastes salty"/>
</LINK>

<LINK type="outcome"> # The following node is an outcome.
<TARGET id="cake is done"/> # This is a "state" node.
</LINK>
```

<LINK type="steps"> # This is a list of the steps in this procedure.
<TARGET id="mix ingredients"/> # These are "procedure" nodes.
<TARGET id="put in oven"/>
<TARGET id="test for doneness"/>
<TARGET id="cool"/>
</LINK>

<LINK type="related-to"> # Other related nodes.
<TARGET id="baked good"/>
</LINK>

</PROCEDURE>
This marks the end of this procedure.

<PROCEDURE id="mix ingredients">
This is the beginning of a new procedure. Notice that this is the first step in the
procedure we just defined above. Procedures are defined hierarchically.

<TITLE>Mix the Ingredients</TITLE>
<AUTHOR>Colleen Kehoe</AUTHOR>

<DESCRIPTION>
Get all the ingredients together and mix them.
</DESCRIPTION>
For this application, we've provided two descriptions, both text.

<DESCRIPTION type="high">
You will need: 2 eggs, 2 c. flour, 1/2 c. milk, 3 tbsp. butter, 1 tsp. baking soda, 1/4 tsp. salt, 1/4 c. water, 1c. sugar. Combine the dry ingredients in one bowl. Combine the wet ingredients in another bowl. Gradually add the dry to the wet, blending with an electric mixer.
</DESCRIPTION>
Here, we provide a very detailed description.

As before, we list the links from this node to other nodes in the system.

<LINK type="uses"> # This is a list of the equipment this procedure uses.
<TARGET id="mixer"/> # This is a "thing" node.
</LINK>

</PROCEDURE>

These are the rest of the steps in the "cake 1" procedure.
Details are omitted in the interest of space, but they would be similar to the one above.

<PROCEDURE id="put in oven">...</PROCEDURE>

<PROCEDURE id="test for doneness">...</PROCEDURE>

<PROCEDURE id="cool">...</PROCEDURE>

<THING id="baked good">
Now we define a "thing" node. This is referred to in the "cake 1" procedure above.

<TITLE>Baked Good</TITLE>
<AUTHOR>Colleen Kehoe</AUTHOR>

<DESCRIPTION>
A baked good is usually found in a bakery. They are things like: bread, cookies, cakes, muffins, etc.
</DESCRIPTION>

<COUNTEREXAMPLE>
<MEDIA SRC="fish.mov" CAPTION="While a fish can be baked, it is not considered to be a baked good."/>
</COUNTEREXAMPLE>
Here, we provide a counterexample to a baked good.
It is in an external media file, but we provide a textual caption as well.

</THING>
#This marks the end of the thing node.

<STATE id="cake didn't rise">
Now we define a "state" node. This was one of the problem states referred to in the "cake 1" procedure.

<TITLE>Cake didn't rise properly</TITLE>
<AUTHOR>Colleen Kehoe</AUTHOR>

```
<DESCRIPTION>
The cake didn't rise above the edge of the pan. This is usually caused by accidentally leaving out the baking powder
or salt.
</DESCRIPTION>

<LINK type="repair-procedure"> # These are links to repair procedures.
<TARGET id="eat it anyway"/> # These are "procedure" nodes.
<TARGET id="feed to birds"/>
</LINK>

<LINK type="related-to"> # This is a link to a related node (here, a similar problem).
<TARGET id="cake cracked"/> # This is a state.
</LINK>

</STATE>

# Other procedures, things, and states are defined similarly.

</PML> # This marks the end of the PML document.
```

Exploring Interface Options in Multimedia Educational Environments

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Introduction

Multimedia technology allows information to be organized and represented in a wide variety of ways. For a computer-based educational environment to be effective, the subject matter must be presented in a clear and comprehensible format. Many multimedia applications organize information based on its physical format, i.e., sound clips, still images, text, and so on. However it is also possible to organize information based on the learner's plan to use information. Such "cognitive media types", media organized around cognition rather than physical format, include definitions, examples, worked problems, and problem sets [Recker, Ram, Shikano, Li & Stasko 1995].

AlgoNet was an educational multimedia environment designed to test the effectiveness of these cognitive media types. Subjects using AlgoNet's cognitive media organization fared significantly better in a post-test than those using a traditional physical media organization [Recker et al. 1995]. While AlgoNet did show that cognitive media types helped students learn, how to best interface cognitive media types into a learning environment remained an open question. AlgoNet2 was created in order to explore some of the possible interface options for supporting cognitive multimedia. AlgoNet2 includes exactly the same domain information as AlgoNet, but with several new enhancements that allow users to navigate more easily and keep better track of their progress through the system.

In order to test AlgoNet2 in a real-life situation, we deployed the system in an introductory undergraduate computer science class at the Georgia Institute of Technology. The results of our study provide insights into the factors important in the design of a computer-based educational environment.

The AlgoNet2 System

The AlgoNet2 program is a prototype of an educational software package incorporating multimedia technology combined with features applying recent findings in cognitive science. AlgoNet2 is the second version of a computer learning environment that is being developed to explore possible interfaces for cognitive media learning environments. This version, as its predecessor, AlgoNet, teaches basic concepts in graph theory.

Figure 1 shows a typical AlgoNet screen. Domain information is presented in the large window in the upper left hand corner of the screen. To the right of the domain window is the *Topic Tree & History* window. This window provides information about the organization of the domain information, the user's current position within the system, and a graphical trace of pages the user has visited. In the lower left part of the screen are four cognitive media buttons that provide access to different kinds of cognitive media. In the box on the lower right, users can select from a list of questions to ask about the current topic. The bottom edge of the screen contains buttons for moving back to the last node visited, invoking the help system, and for exiting AlgoNet2.

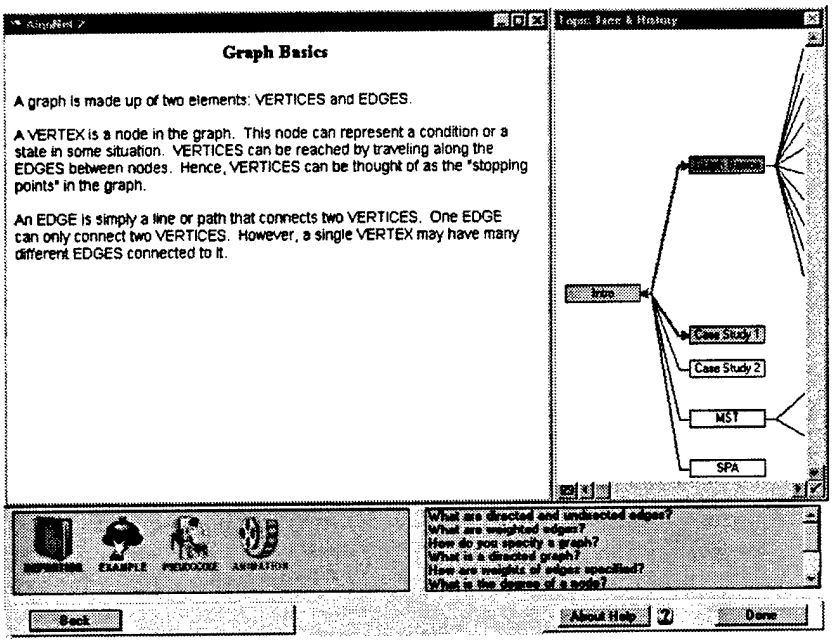

Figure 1: A Typical AlgoNet2 Screen.

Just as in AlgoNet, information presented in AlgoNet2 is divided into groups of pages. Each of these groups (or nodes) covers exactly one topic. Each page within a node belongs to one of four cognitive media types: *definitions*, *examples*, *pseudocode*, and *animations* (dynamic visualizations).

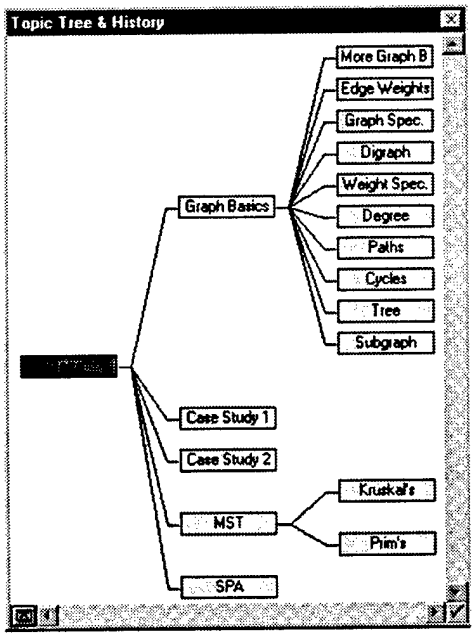

Figure 2: The Topic Tree and History Window.

To allow access to pages within the current node, we provide graphical buttons for the cognitive media types (Figure 1, lower left corner). The small images simplify the mental association between the button and content or type of domain information "behind" it. The current active view is highlighted. Buttons corresponding to cognitive media types unavailable in the current node are "ghosted" and drawn in light gray. The four graphical

buttons remain on the screen at all times, unlike AlgoNet's buttons which were simple text boxes that changed from node to node.

AlgoNet2 allows for two different types of navigation between topics (nodes). One of these navigation styles was based on the idea that it would be very natural and familiar for a student to ask questions about the current topic. To avoid the rigors of natural language understanding, we instead presented a box with pre-formulated questions for each topic (Figure 1, lower right). When the user clicks on a question, a related topic containing the answer to this question is shown. The "back" button allows users to return to the previously visited node. It was hoped that the question-based format would encourage students to ask questions of both their peers and instructors as well as themselves. This question asking/answering behavior has been linked to learning goals [Chi, Bassok, Lewis, Reinmann & Glasser 1988; Chi & VanLehn 1991; Ng & Bereiter 1991; Ram 1991; Ram & Leake 1995; VanLehn & Chi 1992]. We intentionally omitted a "next page" function (contained in the original AlgoNet) that allows users to proceed through the system in some pre-formulated, linear fashion. By removing this feature we forced the users to choose their own paths through the system, hoping to encouraging active learning and reflection on learning goals and strategies.

Another new feature in AlgoNet2 was the *Topic Tree & History* window. This window provides a hierarchical, "bird's eye" view of the information in AlgoNet2. Each node is an instance or type of its parent, e.g., *cycles* and *paths* are two types of *graph basics*. We anticipated that adding this structure to the domain information would encourage students to incorporate a similar structure in their own mental models, facilitating the retention of the material.

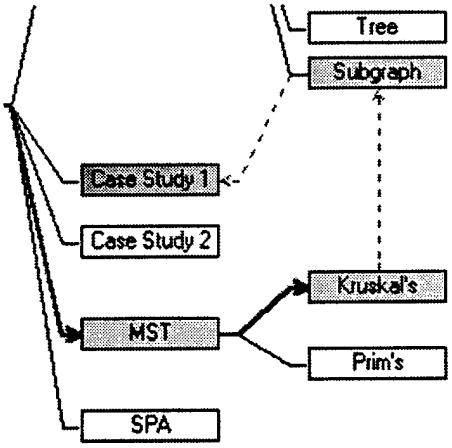

Figure 3. Topic tree links are shown as solid lines. User generated jumps are represented as dotted lines.

In addition to the question-asking interface, a student can also move directly to any node by clicking the appropriate node on the topic tree. As the student navigates, the topic tree provides feedback, relating which nodes have been most recently visited as well as which nodes have yet to be visited. This additional information was intended to prevent the user from becoming lost in a tangle of pages and links, a common problem with hypermedia-based systems. The topic tree color codes the nodes. The current node is highlighted with a light red background. All previously visited nodes have a light blue background. Unvisited nodes are rendered light gray. A history of the last seven steps is provided by color-coding the links between nodes drawn using a "hot to cold" metaphor. The most recently used link is indicated by a bright red arrow, the next six most recently used links are colored various shades from orange to blue, blue being the least recently used link. Links used more than seven steps ago, or not at all, are represented as thin, black lines. In the topic tree, we distinguish between "regular" moves within the topic tree (solid lines) and random jumps to other parts of the system (dashed lines) (Figure 3). This color-coded path through the topic tree is provided in order to give context to the current node, helping to answer questions such as "Why did I come to this node in the first place?" "What information was I looking for?" and "What do I do with it when I have found it?"

Evaluation

The AlgoNet2 system was evaluated in anticipation of fielding the system as a routine component of the introductory level computer science curriculum at Georgia Tech. Participants in the empirical studies were 148 students enrolled in a first-year introductory computer science course. The AlgoNet2 study was designed to take the place of one of the regular laboratory sessions in this course.

One goal of the empirical study was to determine the extent to which students could use the system as a stand-alone module for self-directed learning. As such, the subject material included in the AlgoNet2 system was not covered in classroom lectures. In addition, no formal instructions were given to the participants on the use of the system itself.

The laboratory sessions in this course are not normally designed to provide students with hands-on experience in computer problem-solving. In order to evaluate the system in as natural a setting as possible, the empirical studies were conducted within the context of a routine laboratory assignment and were directed by the students' normal laboratory instructors and teaching assistants. Our lab assignment asked students to solve a problem involving graph theory imbedded in a situation from the popular computer game Doom. By applying graph theory to a graph representing a part of one level of the game, students were able to "win" the game and solve the lab.

The students were given a lab assignment and were told only that AlgoNet2 would be of assistance in completing the assignment. In order to successfully complete the lab assignment, students needed to learn an appropriate graph algorithm and underlying concepts, (one of two "minimum spanning tree" algorithms) from among those presented in the system and then execute the algorithm. No attempt was made to explicitly direct students to specific graph concepts or definitions.

After completing the lab assignment, the students were directed to exit AlgoNet2 and complete a post-lab questionnaire. The questionnaire elicited personal information from each student (e.g., about their previous computer experience) and asked some general system evaluation questions. The questionnaire also included a section that contained questions designed to test the students' understanding of some basic graph concepts.

In addition to the lab assignment and the post-lab questionnaire, there were two other sources of data. The AlgoNet2 system automatically logged each participant's interactions with the system. We also videotaped four volunteers to help identify any system usage difficulties or other activities of interest.

Results

Navigation Method	Rationale	Average Uses per Student
Question-Asking Interface	Natural method of inquiry, encourages metacognition.	4.2
Topic Tree	Puts current node in context, shows overall layout of system, shows users where they've been.	22.6
Cognitive Media Icons	Provides consistent, easy access to the cognitive media types.	14.6

Table 1: Students used the topic tree far more often than the question-asking interface.

Recall that students had three different ways of navigating through the AlgoNet2. Table 4 recounts these methods and the rationale behind each one. The right hand column shows the average number of times each student used each type of navigation. Users used the topic tree far more than the question-asking interface even though the two provide essential the same functionality: the ability to move between different nodes in the system.

Overall, users showed a slight preference for examples and visualizations over pseudocodes and definitions. However there was no significant correlation between users' experience levels and their preference for one cognitive media type over another. Over two-thirds (68%) of the students responding said that they were satisfied with the AlgoNet2 system in the post-lab survey.

Students tended to view visualizations far longer than any other form of cognitive media type as measured by the amount of time spent with each media type (Figure 4). This tendency to dwell on visualizations was echoed in the original AlgoNet study [Recker et al. 1995].

Analysis of the numerical data produced several meaningful and statistically significant correlations. Students' time viewing the visualization was positively correlated with their performance on the lab assignment, ($r = .290, p < .01$). SAT-verbal scores were negatively correlated with time viewing the mostly textual definition and

example pages, (r = .335, p < .01). SAT-verbal scores were also negatively correlated with use of the question-asking interface (r = -.211, p < .05). Number of uses of the topic tree interface was negatively correlated with the students' self-report of the difficulty of the lab (r = .192, p < .1). Post-lab quiz scores correlated positively with students' viewing times for definitions and examples (r = .323 and .215 respectively, both at p < .05).

Some correlations were conspicuously absent. Previous background, including major field, SAT scores, and previous computer science background had no significant bearing on students' performance on the lab or the post-lab quiz.

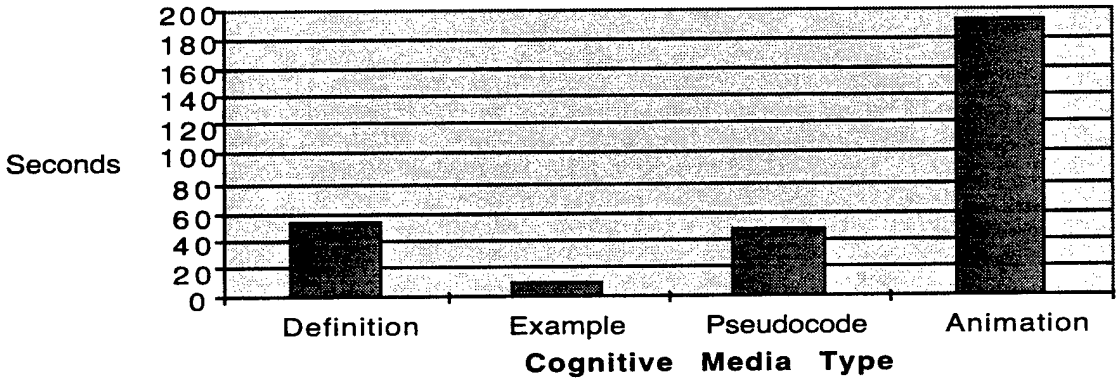

Figure 4. Relative viewing times for cognitive media types. Students spent more than three times as much time viewing visualizations as any other media type.

Discussion

Student reports of the difficulty of the lab were negatively correlated with their usage of the topic tree. Students using the topic tree more often found the lab to be easier overall. While this result is purely correlational, we are hopeful that we can demonstrate that our experimental interface does in fact increase ease-of-use.

The question-asking interface and the topic tree both provide the same function: the ability to move from one node to the next. However, the students used the topic tree far more than the question-asking interface. One reason for this difference might be that the topic tree allowed instant access to any node in the entire system while the question-asking interface only allows one-hop moves along the topic tree. The students' preference for the topic tree may be pure convenience. Alternately, the larger, more graphical topic tree may draw the students' attention. Finally, the topic tree may actually be a more comprehensible interface. Additional research is needed to explore these possibilities.

The negative correlation between SAT-verbal scores and time viewing definitions (which tend to be composed of plain-English definitions of concepts) can be explained in the following way: highly verbal students viewed the same number of definitions and examples, but needed less time to absorb the same amount of content as less-verbal students. This suggests that students with different abilities use cognitive media types differently.

One of the clearest messages in the log data is that "glitzy" multimedia, i.e., fancy animations, is not an atheoretical luxury. Multimedia is capable of capturing and holding the subject's attention far better than any other media type we studied. There was only one visualization in the entire system, but users spent far more time at this page than of any other category of page. This finding is confirmed by the post-lab questionnaire as well. When asked what the system lacked, students often requested more multimedia support. Students' suggestions ranged from, "More animations for algorithms," to "Add kewl (sic) sounds."

When queried on their learning strategies, very few students could give a clear answer, if any at all. Of the students responding to the question, the most common strategies cited were "wander randomly," and "read everything." Students also reported frustration with this type of instruction, citing a lack of "direction" and "what to do next information." This clearly demonstrates that our question-asking protocol was not enough to encourage students to effectively guide their own thinking process and suggests that there is a need for the effective teaching of learning strategies.

While students were unable to identify their learning strategies, experimenters circulating through the labs did notice a consistent learning strategy. Many students tended to scan all of the content information quickly, then begin solving the lab. As they worked on their lab, students often returned to the AlgoNet2 system, suggesting that

they were actively hunting for information they needed. This suggests that students do use learning strategies, but may not be aware of them.

Future Work

Our pilot study of AlgoNet2 produced large amounts of data. Our next step will be to continue the analysis of the data and report any additional trends discovered. When all the data have been analyzed, we will begin work on AlgoNet3, a third version of the AlgoNet system which will include more cognitive media types such as problem sets and worked problems as well as more multimedia and interactive components. The next system will also be applied to domains outside of graph theory.

Future versions of AlgoNet can be useful in three distinct ways. First, they can be deployed in actual classrooms as instructional tools. Second, we can continue to study students' interaction with the systems in order to refine the learning environments and develop design guidelines as we have done in this paper. Finally, future systems can help us explore the learning itself, revealing students' strategies and understandings of their own learning processes.

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The Role of Student Tasks in Accessing Cognitive Media Types

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Abstract: We believe that identifying media by their cognitive roles (e.g., definition, explanation, pseudo-code, visualization) can improve comprehension and usability in hypermedia systems designed for learning. We refer to media links organized around their cognitive role as cognitive media types [Recker, Ram, Shikano, Li, & Stasko, 1995]. Our hypothesis is that the goals that students bring to the learning task will affect how they will use the hypermedia support system [Ram & Leake, 1995]. We explored student use of a hypermedia system based on cognitive media types where students performed different orienting tasks: undirected, browsing in order to answer specific questions, problem-solving, and problem-solving with prompted self-explanations. We found significant differences in use behavior between problem-solving and browsing students, though no learning differences.

Introduction

Hypermedia is typically oriented around physical media types, for instance, text, video, graphics, and audio. The World Wide Web's use of Mime types, which are based on physical characteristics, is a good example [Berners-Lee, Cailliau, Luotonen, Nielsen, & Secret, 1994]. We believe that identifying media by their cognitive roles (e.g., definition, explanation, pseudo-code, visualization) can improve comprehension and usability in hypermedia systems designed for learning. We refer to media links organized around their cognitive role as *cognitive media types*. In a recent study, students using a hypermedia system organized around cognitive media types performed better on a post-test on the content in the system than students using a hypermedia system organized around physical media types [Recker, et al., 1995].

However, we also believe that the goals that students bring to the learning task will affect how the students will use the hypermedia support system [Ram & Leake, 1995]. Certainly, the system can be tuned to different tasks. Researchers working on the Superbook hypermedia system found that different interfaces better supported either browsing activity or searching for a particular kind of information [Egan, Remde, Gomez, Landauer, Eberhardt, et al., 1990]. Our question was whether setting different tasks for students (and thus, different goals) would affect (a) how students utilized cognitive media types and (b) student learning.

In particular, we explored two kinds of task differences:

- *Problem-solving vs. browsing:* We hypothesized that students who had a specific problem to solve would access the hypermedia organized around cognitive media types differently and would learn more than students who were more or less simply browsing for interesting content.
- *Self-explanations:* The work of Chi and others [Chi, 1992] [Chi, Bassok, Lewis, Reimman, & Glaser, 1990] suggests that students who self-explain the content and their actions learn more effectively than those who do not self-explain. We hypothesized that we might be able to prompt students to self-explain based on their activity in the hypermedia system to achieve gains in learning. Our efforts here are similar to those of [Bielaczyc, Pirolli, & Brown, 1991] [Bielaczyc & Recker, 1991] who also engineered prompts to encourage and teach self-explanation behavior. Our additional question was whether students prompted for self-explanations would access the cognitive media types differently than students without such prompts.

Self-explanation prompts are less interesting in a browsing condition than in a problem-solving condition

because there is less student activity to explain. Therefore, we only used self-explanation prompts as a second problem-solving condition. We note, however, that the prompts in a self-explanation condition can also serve to direct student exploration. To explore that role, we had two browsing conditions – one without direction, and one directed to answer specific questions.

Methods

In an attempt to test some of our ideas about cognitive media types, students' tasks, and self-explanation, we designed instructional software for teaching students how to solve problems involving the determination of molecular shape. This subject is particularly difficult for introductory Chemistry students so the potential benefits in this domain are considerable.

The software, which we called ChemLab, is based on an outline of the problem solution procedure developed by our domain expert (P. Ram). The steps in the procedure are laid out in a map that students can follow to arrive at a solution. There are 22 steps in the procedure that the students could examine. Each step contained up to four cognitive media types:

1) *Definitions*. Key concepts relevant to this step and the operations required at this step of the procedure were presented here.

2) *Examples*. Concrete examples of this step in the procedure or the key concept in the step were presented here.

3) *Worked problems*. This was generally a "before and after" presentation in which the students saw a partial solution before the step was performed and then after it was performed. Explanations for the operations were also present.

4) *Problem sets*. This was similar to a worked problem but provides an opportunity to test one's knowledge. The screen presents a "before the step" situation and asked the learner to execute the step in their head or on scratch paper. The learner could request that the solution then be shown to verify their solution.

Because this particular domain is very visual, ChemLab makes extensive use of figures along with the text [see Fig. 1]. However, use of other physical media types were limited. The semi-public computer cluster environment constrained our ability to make use of sound and time constraints made construction of animations impossible. Future versions of ChemLab will make more extensive use of animation to illustrate the more dynamic content, though the use of sound is still an unresolved issue.

Subjects

The subjects in the ChemLab experiment were approximately 80 undergraduates who were taking an introductory Chemistry course at Emory University. They participated in the experiment for extra-credit. Subjects had attended lectures (scattered over a two week period) in their course which addressed the material covered in ChemLab.

The participant sample was a strong group of students with a self-reported grade-point average of 3.4 out of 4.0 and mean SAT scores of 571 on the Verbal scale and 663 on the Quantitative scale. Thus, it was a very capable group that used the ChemLab software. Random assignment procedures were effective in that there were no mean group differences on any of these participant variables.

Apparatus/Materials

Subjects were given paper guides to help them navigate the ChemLab software. The software itself was run on Macintosh Centris personal computers and developed in Apple's HyperCard (version 2.3).

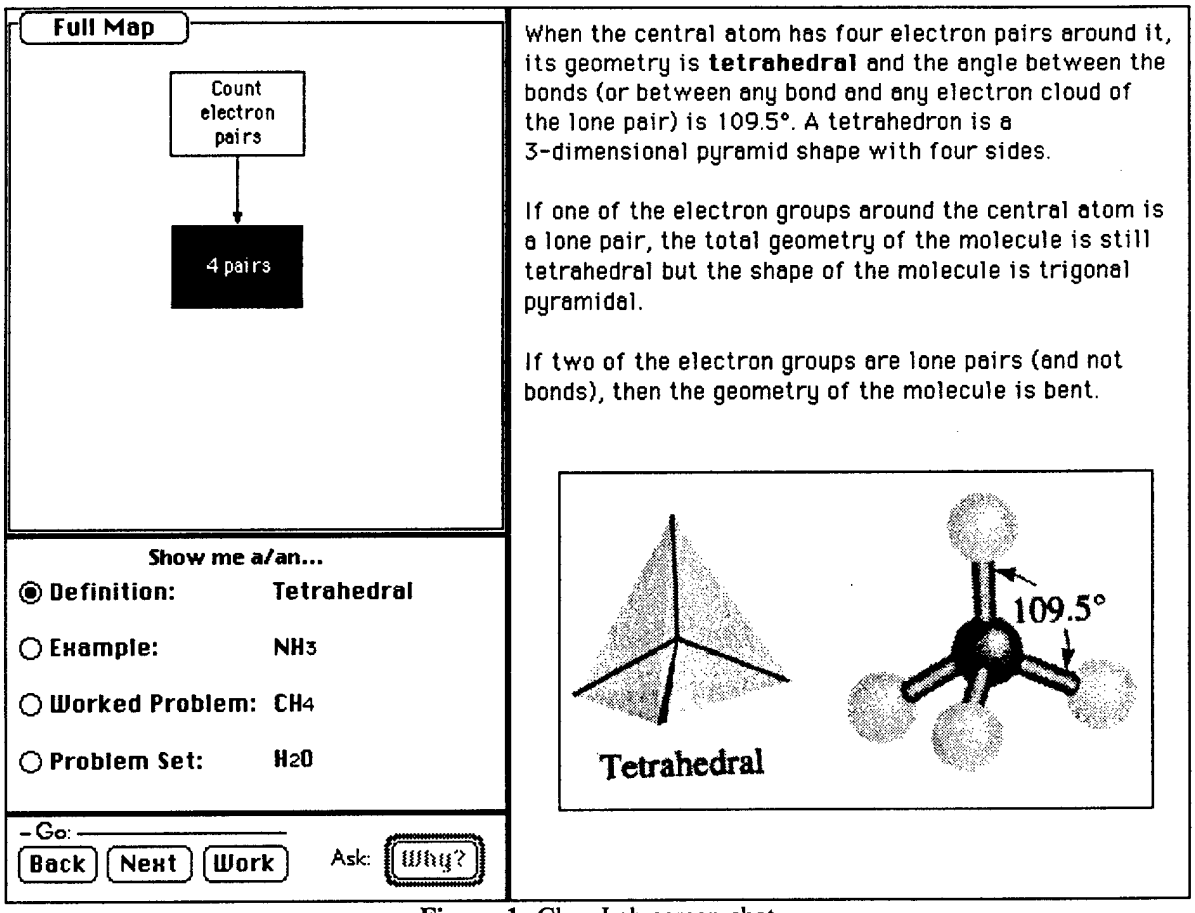

Figure 1: ChemLab screen shot

Design

All subjects had access to the same instructional material in the software and were given the same post-test after using the software. The post-test was a short quiz designed by the regular Chemistry instructors for the course. The ChemLab software also kept a log of mouse clicks so it was possible to analyze browsing patterns for the subjects.

The presentation of the ChemLab software was in slightly different contexts for different subjects. There were four presentation groups:

1) *Passive watching*. In this condition, subjects were given access to the ChemLab instructional material and little guidance. They were instructed to "work through the materials until you are pretty sure you are prepared to solve some problems." This is, in essence, the control condition.

2) *Directed watching*. In this condition, we wanted to give the subjects some learning goals while browsing through ChemLab. Thus, subjects were given a series of questions to answer to help guide their browsing. These questions concerned different aspects: some were oriented towards the procedure (e.g. "how do you do X?" or "what do you do after step Y?"), some were oriented toward specific content (e.g. "what's the chemical formula for Hydrazine?"), some were definitions, and many were purposely obscure things that subjects would have to find as distractors.

3) *Problem solving*. Subjects in this condition could not only browse ChemLab, but were asked to solve two specific molecular shape problems. As they were doing so, they were allowed to use ChemLab as a resource to help them solve the problems. This condition was included to encourage subjects to spontaneously generate learning goals directly relevant to solving real problems.

4) *Problem solving with prompting*. This condition was identical to condition 3 with one addition: at various points while subjects solved the problems, they were prompted to explain what they were doing and why. It was hoped that this manipulation would increase reflection and self-explanation.

Subjects in the two problem-solving conditions were asked to use special software called the Molecule Construction Kit to solve the problems [see Fig. 2]. This made the whole environment more self-contained and gave us the opportunity to examine partial solutions.

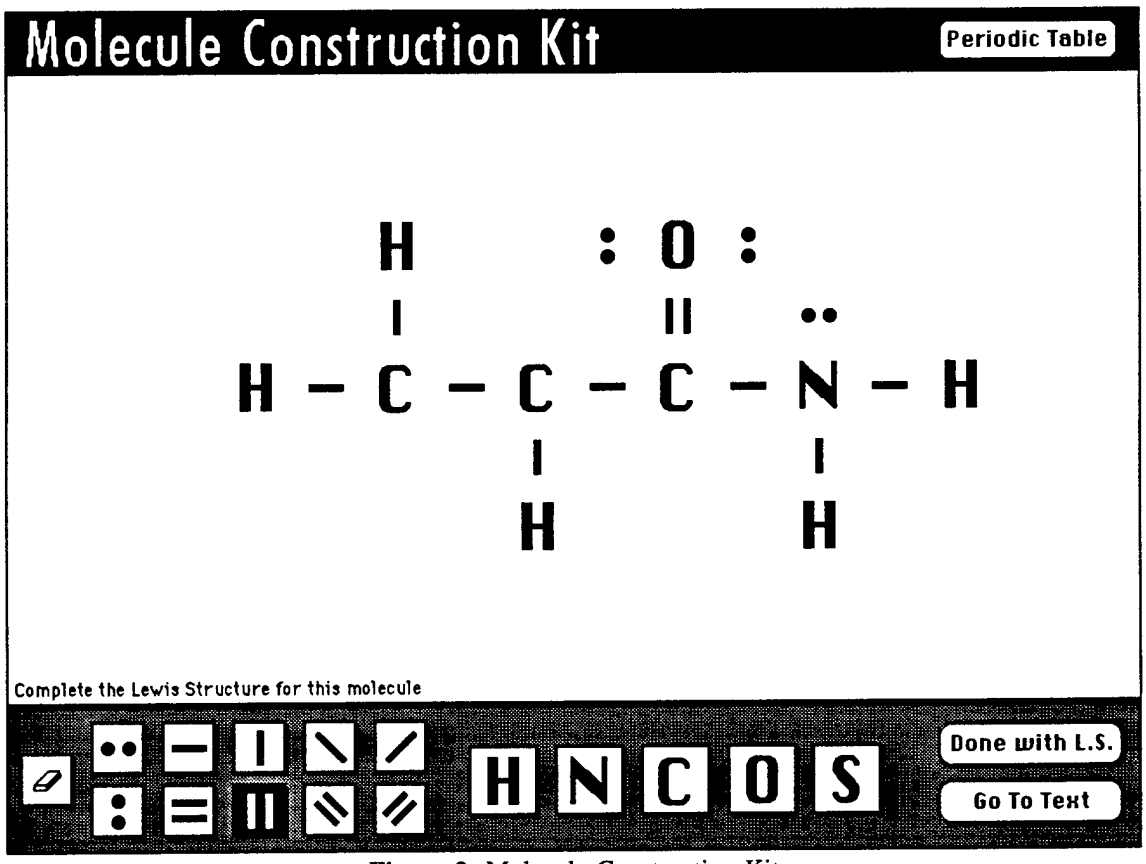

Figure 2: Molecule Construction Kit

Procedures

Participants first filled out the consent form. After this, they were allowed to spend as much time as they wanted with the ChemLab software. The software also prompted them to report their grade-point average and SAT scores. Once they were satisfied with the time they had spent using ChemLab, they received a brief questionnaire asking them to rate their confidence in their ability to solve molecular shape problems. Once they had completed the questionnaire, they were given the post-test on paper. They were proctored during the post-test and given unlimited time to solve the problems on the quiz.

An example problem on the post-test was: *Arrange the following species in order of decreasing F--A--F bond angles, where A is the central atom: BF3, BeF2, CF4.* The correct solution was BeF2, BF3, CF4.

Results

Browsing patterns were clearly affected by the condition to which subjects were assigned. Subjects in the problem-solving conditions visited an average of only 5.4 of the 22 steps, while subjects in the browsing conditions visited an average of 17.6 of the 22 steps, and this difference is reliable ($F(1,74) = 82.70$, $p < 0.001$). This is an extremely large difference; on average, subjects in the problem-solving conditions saw less than one-fourth of the steps in the procedure while browsing subjects saw 80% of the steps. This difference carried into the number of visits to the different media types; for all four media types, subjects in the browsing conditions had more visits than subjects in the problem-solving conditions.

This may have been compensated for by the amount of time subjects spent looking at the screens when they were presented. An average visit to a screen for the subjects in the browsing conditions lasted 36 seconds, while for the problem-solving subjects the average visit lasted 86 seconds. Again, this difference is reliable ($F(1,43) = 12.10$, $p =$

0.001) and is quite large; subjects in the problem-solving conditions spent almost two and a half times as long looking at a screen of information than subjects in the browsing conditions. The average total time (not including reading the initial instructions) for the experiment was 17.85 minutes. This was weakly related to post-test score ($r(77) = 0.62$, $p = 0.058$).

While there were clear effects on browsing patterns for problem-solving vs. browsing, there were no effects associated with prompting except the total amount of time spent using ChemLab. The source of this difference is probably the extra typing subjects in the prompted condition did in answering the prompts. In any case, the difference here, though reliable, was not large.

Unfortunately, there were no reliable differences in post-test scores between the groups. Table 1 summarizes the four groups' post-test scores. Overall, subjects did reasonably well on the post-test, averaging 8.15 points of a possible 10. Interestingly, self-reported confidence (the rating taken right before the post-test) was only weakly correlated with the actual quiz scores, $r(80) = 0.20$, $p = 0.07$; self-reported confidence was more highly correlated with SAT Quantitative scores $r(69) = 0.28$, $p = 0.02$ even though SAT scores were not correlated with quiz performance.

Group	Average Score	Standard Deviation
1	8.34	1.91
2	8.34	1.26
3	8.00	1.52
4	7.96	1.59

Table 1: Summarizing Four Groups' Post-Test Scores

Discussion

The lack of differences between groups' post-test scores are surprising – our hypotheses predicted differences both in browsing behavior (which was observed) and in learning performance (which was not). However, this lack of difference might be attributed to the complexity of the task (or rather, lack thereof) and student ability. The students were very capable, and even those who received relatively little support from the hypermedia system (i.e., the problem-solving group students who saw less than 25% of the steps in the procedures) performed very well on the post-test (8.15 out of 10 points, with a standard deviation of less than 2.0 – almost nobody got less than half the quiz right), which may also suggest a ceiling effect. The students were doing so well that there was little opportunity to discover group differences.

More interesting is the dramatic differences between use patterns among the groups. Students who were trying to solve a problem visited fewer cognitive media types but spent more time studying the media that they did visit. It may be that if the task were more complex and the students needed more of the information in the hypermedia system to solve the task, as opposed to having seen much of the information in class already, the differences in use behaviors might result in greater differences in performance on the learning task and on the post-test.

The observation that problem-solving students spent more time studying the screens is in marked contrast with prevailing wisdom in hypermedia design. Generally, hypermedia designers reduce the amount of text in their systems in favor of more "glitzy" media, such as graphics, sound, and video, arguing that users are not willing to spend the time reading text. In fact, some researchers have even claimed that reading will become an obsolete skill as multimedia computers become more common [Papert, 1993]. While the case and value of "glitz" is real and important, our data suggest that if users are actively trying to problem-solve and use the content in a hypermedia system, they will invest the time on the content, perhaps even reading the text.

Our results offer no insights on the question of self-explanation prompts. We have no evidence of differences in learning performance nor of differences in use behavior due to self-explanation prompts, other than the time differences required to respond to the prompts. It may be that if we were to repeat the experiment with a more complex task and with more necessary hypermedia content, then students might be more motivated to respond to the prompts more thoughtfully, resulting in greater learning differences.

Conclusions

While we have not been able to support our hypotheses about self-explanation and about learning effects, our results do support the hypothesis that a difference in user task will cause a difference in browsing behavior. Thus, there are several paths of interest for future work:

- Certainly, repeating the experiment with a more complex task where hypermedia support is more critical might provide useful insights on the learning question. Since the problem-solving students spend more time studying content but view less of the overall system, good navigation mechanisms that lead these students to the necessary content will be a critical feature of future systems [Shippey, Ram, Albrecht, Roberts, Guzdial, et al., 1996].
- Time spent on the content suggests an interesting avenue for an exploration where the relative amounts of different cognitive media types are varied to investigate further the relationship between media types, task, and learning.
- Varying the kinds of physical media corresponding to cognitive media and varying the kinds of interaction with the system offers another interesting interface component whose use may vary with task.

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